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A SURVEY OF ANTENNAS FOR ULTRA-WIDEBAND APPLICATIONS (POSTPRINT)

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Tennessee State University

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14. ABSTRACT
The usage of ultra-wideband (UWB) technology is growing in many communication systems such as radar systems, communication and measurement systems and imaging systems mainly because unlike the other wireless technologies UWB is not restricted to using a narrow waveband and it has high speed data rate. The large transmission bandwidth makes UWB-based electronic device resistive to interferences and gives immunity against getting detected. Typical operational frequency range of the UWB devices varies from few 100s MHz to 10 GHz. However, the most popular UWB devices are designed to operate between 1-3 GHz. This paper presents an overview of different types of commercially available antennas suitable for UWB applications. The paper begins with the basics of understanding of antennas properties. Next, it discusses the main antenna characteristics like: radiation pattern (directional or omni-directional), gain, bandwidth, size, etc for different UWB applications and explains criterions for quantitative and qualitative performance measure of the antennas. The antennas covered in this paper include: TEM Horn, Folded horn, Dipole, Planner Fat Dipole, Cross Dipole, Rolled Dipole, UWB dielectric, Bowtie, Wire Bowtie, etc. This paper describes the pros and cons of each antenna and highlights the application areas of each antenna. Lastly, this paper summaries the important characteristics of the antennas and presents several promising directions for future enhancement of UWB antenna systems.

15. SUBJECT TERMS ultra-wideband (UWB), ground penetration radar (GPR), directivity, radiation pattern, gain, and bandwidth

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A Survey of Antennas for Ultra-wideband Applications

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ABSTRACT

The usage of ultra-wideband (UWB) technology is growing in many communication systems such as radar systems, communication and measurement systems and imaging systems mainly because unlike the other wireless technologies UWB is not restricted to using a narrow waveband and it has high speed data rate. The large transmission bandwidth makes UWB-based electronic device resistive to interferences and gives immunity against getting detected. Typical operational frequency range of the UWB devices varies from few 100s MHz to 10 GHz. However, the most popular UWB devices are designed to operate between 1-3 GHz. This paper presents an overview of different types of commercially available antennas suitable for UWB applications. The paper begins with the basics of understanding of antennas properties. Next, it discusses the main antenna characteristics like: radiation pattern (directional or omni-directional), gain, bandwidth, size, etc for different UWB applications and explains criterions for quantitative and qualitative performance measure of the antennas. The antennas covered in this paper include: TEM Horn, Folded horn, Dipole, Planner Fat Dipole, Cross Dipole, Rolled Dipole, UWB dielectric, Bowtie, Wire Bowtie, etc. This paper describes the pros and cons of each antenna and highlights the application areas of each antenna. Lastly, this paper summaries the important characteristics of the antennas and presents several promising directions for future enhancement of UWB antenna systems.

Keywords: Ultra-wideband (UWB), Ground Penetration Radar (GPR), directivity, radiation pattern, gain, and bandwidth

1. INTRODUCTION

There is high demand for the UWB technology in many communication systems. These systems include the radar systems, communication and measurement systems and imaging systems. These systems have several subsystems within their systems; however, the antenna is a common subsystem in all of these communication systems. In addition, the antenna is one of the important components in any wireless communication system because it should make an efficient interface between the electronics inside the system and the outside world [1]. All of the antennas regardless UWB or traditional they are characterized by common features such as: operational frequency bandwidth, radiation pattern, voltage standing wave ratio (VSWR), efficiency, directivity, gain, polarization, etc. The design of a UWB antenna, in particular, is more challenging in compare with to the other types of antenna because these antennas should maintain their characteristics on entire frequency band of their operation. Peyrot-Solis *et al* [2] conducted a survey on wide variety of microstrip UWB antennas and planar monopole antennas particularly within the range of the 3-10 GHz. The focus of the current paper is surveying of ultra-wideband antennas with particular emphasis on the ground penetration radar antennas. Ground Penetrating Radars (GPRs) or surface penetrating radars have wide variety of applications such as archaeology, civil engineering, forensic applications, geophysical application, mine detection, utilities, and remote sensing applications.

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2. FUNDAMENTAL OF ULTRA-WIDEBAND

2.1. Fundamental of the Antennas

Webster's Dictionary defines an antenna as "a usually metallic device (as a rod or wire) for radiating or receiving radio waves". According to the *IEEE Standard Definitions of Terms for Antennas* (IEEE Std 145-1993) an antenna is defined as: "That part of a transmitting or receiving system that is designed to radiate or to receive electromagnetic waves" [3]. The radiation pattern or antenna pattern of an antenna is defined as "The spatial distribution of a quantity that characterizes the electromagnetic field generated by an antenna" [3]. The radiation pattern usually is shown as mathematical function or graphical representation for an antenna. For any antenna the gain in a given direction is defined as "The ratio of the radiation intensity, in a given direction, to the radiation intensity that would be obtained if the power accepted by the antenna were radiated isotropically" [3]. In addition, the directivity is defined as "The ratio of the radiation intensity in a given direction from the antenna to the radiation intensity averaged over all directions" [3]. Moreover, the directional antenna is defined as "An antenna having the property of radiating or receiving electromagnetic waves more effectively in some directions than others" [3]. This characteristic is useful for the long distance communication and remote sensing applications which need more directional antennas [4]. Some of antennas such as horn antennas are more directional in compare to the other antennas. However, combining any antenna in array form improve directional properties of an antenna [4]. This standard also defined the polarization of an antenna as "In a given direction from the antenna, the polarization of the wave transmitted by the antenna" [3]. In addition, the polarization efficiency is defined as "The ratio of the power received by an antenna from a given plane wave of arbitrary polarization to the power that would be received by the same antenna from a plane wave of the same power flux density and direction of propagation, whose state of polarization has been adjusted for a maximum received power" [3]. In other hand, radiation efficiency: is defined as "The ratio of the total power radiated by an antenna to the net power accepted by the antenna from the connected transmitter" [3]. The bandwidth of an antenna is defined as "The range of frequencies within which the performance of the antenna, with respect to some characteristic, conforms to a specified standard" [3]. Based on the bandwidth of an antenna a narrowband / wideband antenna can be defined as "An antenna is said to be narrowband if the fractional bandwidth, defined as:

$$FB = \frac{(f_{upper} - f_{lower})}{f_{center}}$$

and FB is below 1%; otherwise, it is said to be wideband" [4]. When the load and the transmission line are not matching together then some of the energy is absorbed and some is reflected back in the direction of the source. This reflection and transmission creates the standing waves on the transmission line which can be represented as voltage standing wave ratio (VSWR) or ISWR [5]. The ISWR is derived based on the measurement of the current in the transmission line and VSWR derived based on the voltage measurement. The measurement of the SWR shows the energy loss in the transmission line [5].

2.2 Advantages of Ultra-wideband Systems

The UWB systems have several advantages compare to other types of the communication systems. The UWB have potentially low complexity and low cost. These types of systems usually are resistant to severe multipath and jamming. Moreover, they have very good time domain resolution that makes them suitable for tracking and localization applications [6]. This type of the signal also is suitable for radar system because the UWB signal is noise like which causes interception and detection quite complicated. In addition, in contrast to the conventional radio systems, in the UWB systems, the transmitter generates a very short time domain pulse, which is able to propagate without the need for an additional radio frequency (RF) mixing stage [6].

2.3 Ground Penetrating Radar (GPR)

The *IEEE Standard for Ultrawideband Radar Definitions* (IEEE Std 1672-2006) defines the ground penetrating radar as "A UWB radar set for probing and imaging through the earth, rock formations, buildings, bridge decks, archeological sites, crime scenes, etc. Ground penetrating radars generally use impulse signals at relatively low frequencies, e.g., below 5 GHz. Generally built as a specialized impulse radar [7]." Based on this definition the suitable UWB antennas for this application would be the antennas that operate within the certain bands defined by (IEEE Std 521-1984 and 2002). These bands of frequencies are high frequency (HF) or 3 MHz-30 MHz, very high frequency (VHF) or 30 MHz-300 MHz, ultra high frequency (UHF) or 300 MHz-1000 MHz, L band 1 GHz-2 GHz, and S band or 2 GHz-4 GHz. In addition, the International Telecommunications Union has defined the UHF band form 0.3 GHz to 3GHz [8]. The kilohertz frequency operation is used for deep GPR applications [9]. In addition, the frequency ranges between 1-6 GHz are commonly used for shallow GPR applications because it provides good ability of penetration and resolution. There are three requirements for the GPR antennas; these are broad bandwidth, good efficiency, and low antenna clutter [9].

3. UTLTRAWIDEBAND ANTENNAS

3.1 Type of the Antenna

This paper discusses different types of the UWB antenna. Some of these antennas are TEM Horn, Folded horn, Dipole, Planner Fat Dipole, Cross Dipole, Rolled Dipole, UWB dielectric, Bowtie, Wire Bowtie, etc.

3.1.1 Dipole Antennas

There are several types of the dipole antennas. These are planner fat dipole, crossed dipole, rolled dipole, vee dipole etc. A planner fat dipole was designed by Jeong *et al.* for ground penetrating radar system with operation frequencies between 100 to 300 MHz which uses the impulse technology [10]. This antenna was built with substrate of FR4 (ε_r= 4.4). This antenna operates with VSWR less than 1 within its frequency range of operation. In addition, the impedance match for the unit is 50Ω. In this system the antenna and 50Ω coaxial cable are connected by a BNC connector. Figure 1 shows the planner fat dipole and its radiation pattern.

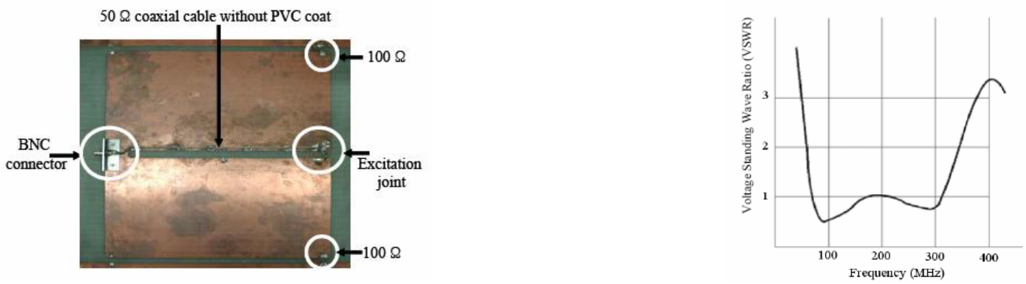


Figure 1: Planner Fat Dipole and Its Radiation Pattern [10]

The other type of the dipole antenna is Cross Dipole Antenna. In ground penetration application, a cross dipole with the arm length of 0.15-m was built by Moffat, Peters, and Chan team to improve the identification of the mine in the landmines. This antenna was replaced their previous antenna which has length of 0.6 m and Balun. This antenna has a gain of approximately 6 dB [11]. The operating range of frequency of the antenna is between 100 to 500MHz. Figure 2 shows the cross dipole antenna.

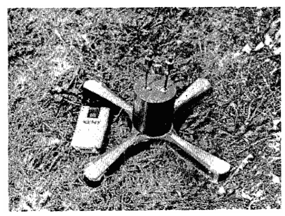


Figure 2: Small Cross Dipole Antenna for Improved Mine Identification [11]

A Rolled Dipole Antenna was proposed by Lestari *et al.* [12] at Radar & Communication System (RCS), Indonesia, for low resolution GPR application. This antenna is designed to operate with monocycle pulses below 500 MHz. The duration of monocycle pulses is 5 ns (200 MHz central frequency) [12]. The total length of wire that was used is 296 cm, but the length of the rolled dipole reduced to 75 cm for this design. The height of this antenna is 31.5 cm. This rolled antenna constructed by the FR4 material and it is combined with the bowtie antenna to increase its efficiency [12]. In addition, measuring input impedance of rolled dipole antenna demonstrates that it has no high-Q resonance [12]. Figure 3 illustrates the rolled dipole antenna.

Figure 3: Rolled Dipole [12]

There are several types of vee dipole antennas. One of these vee dipole antennas was designed by Licul *et al* [13]. The new gain is about 7.5dB and has a significant reduction in back radiation level. In addition, the directivity of the antenna was increased [13]. The radiation pattern of this antenna is analyzed in WIRE software. Their study indicates that the antenna has 1.4 dB improvements in directivity and about 12 dB reduction in back radiation. This new vee dipole has two additional pieces of wire on its arms. The design consists of five independent parameters. The first one is the angle between the main arms; the second one is the angle between director and main arms; the third one is the director's length, the fourth one is orientation of the director on the main arm, and the last one is length of the main arms. The antennas were made out of copper wire with diameter of 0.1mm and were mounted on cardboards. The antenna was tested at frequency of 2.3 GHz [13]. Figure 4 illustrates the vee dipole antenna.

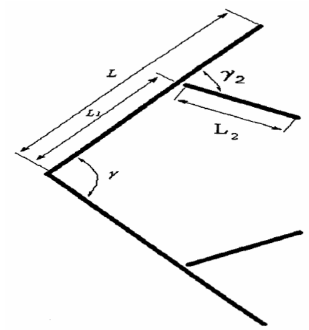


Figure 4: Geometry and Parameters of the Vee Dipole with Director Elements [13]

The resistive loaded vee dipole (RVD) antenna is another antenna that is suitable for the GPR application. Some of the advantages of the RVD are the radiating short-pulse into small spot on the ground, and low radar cross section [14]. According to the Kim-Scott [14], the low radiation efficiency is not an important factor for short-pulse GPR systems, which the antenna operates close to the target [14]. In addition, they note, that the signal to clutter ratio is more important factor for GPR application [14]. A new RVD antenna was designed by the kim-Scott which has additional improvements in terms of VSWR, gain, and front back-to-back ratio of the RVD. In particular, the gain of the antenna was improved by curving the arms of vee loading profile. The curvature of the arms was noted that improves the forward gain of the RVD.

In addition, this feature helps to reduce radiation reflection at the drive point of the antenna [14]. Figure 5 shows the RVD antenna which is designed specifically for GPR application. This RVD was manufactured by printing the arms on a thin (2 mil) flexible Kapton film (ε_r=3.4). Fourteen surface mount resistors loaded on each arm. The length and width of each resistor is 1.25 and 2.0 mm respectively. The number of the resistors was chosen in such a way to prevent the occurrence of resonant frequency at a frequency higher than RDV operation bandwidth. This new RVD antenna was designed to operate at frequency range of 500 MHz to 8 GHz. This new antenna has low radar cross section (RCS) and it is lightweight which is suitable for array application [14].

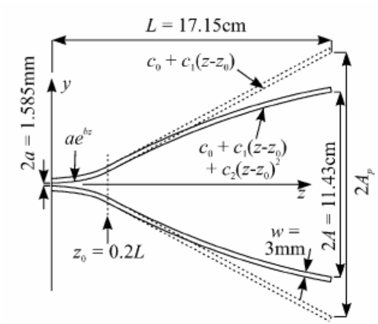


Figure 5: RVD Antenna Designed for GPR Applications [14]

Kim *et al* investigated the efficiency of the resistive vee dipole antennas [15]. In this research a numerical model is used to validate the set of the reflection measurements. The numerical model is based on the method of the moment. The measurements were conducted from 100MHz to 10 GHz. For testing this antenna the 50Ω coaxial cable was connected to the Agilent E8362B PNA and Picosecond Pulse Labs Model 5315A-104 differential pulse splitter balun. Figure 6 illustrates this RVD antenna. The result of the measurement and numerical model are in agreement and they show that this antenna has VSWR <2 between 1-10 GHz. In this research, the FEKO software was used for modeling of this antenna. The FEKO software is commercial EM software that operates based on the method of the moments. The efficiency of the antenna is become essential when the antenna is needed to use in far-field applications like airborne GPR [15].

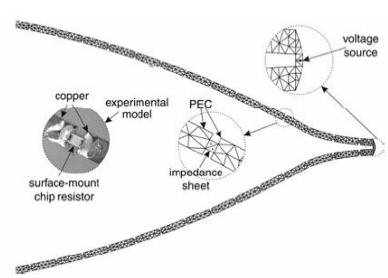


Figure 6: The Resistive Vee Dipole Antenna [15]

In those applications, it is important to keep the desired signal-to- noise ratio, because the antenna should be able to accept and radiate the large power. In addition the input power should not be greater than the power handling capability of the resistors. The result of this research is showed that this antenna can be used in low power applications only [15].

3.1.3 Bowtie

Among the UWB antennas, the bowtie antennas have many advantages, such as low profile, ultra wide impendence band, high radiation efficiency and easy to manufacture etc [16]. One type of the bowtie antenna was introduced by Lestari *et al.* that is called resistive and capacitive (RC) loaded bowtie antenna [17]. The transmission of pulses in this antenna has very small late-time ringing because of the loading scheme of the RC loaded bowtie antenna. In addition this antenna has relatively high radiation efficiency. Moreover, the VSWR of this antenna is less than 2 for frequency range of 0.5-5.1 GHz [17]. Figure 9 shows the RC loaded bowtie antenna. The result of radiation patterns of the RC loaded bowtie antenna in paper [17] indicates that the main beam of this kind of the antenna is relatively stable for frequencies between 1.2 GHz and 3.5 GHz. The figure 10 shows the radiation pattern of the RC loaded bowtie antenna.

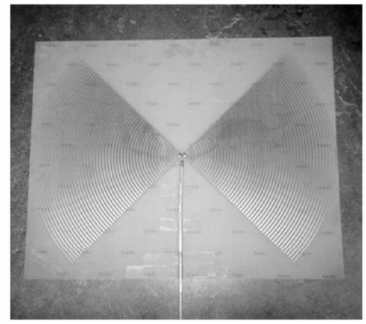


Figure 9: RC Loaded Bowtie Antenna [17]

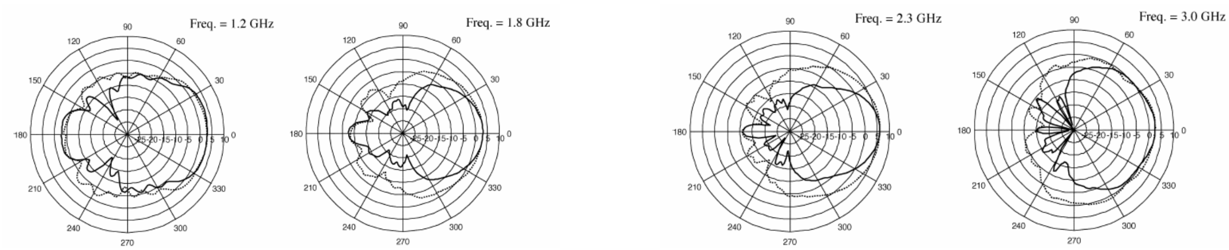


Figure 10: The Radiation Pattern of the RC Loaded Bowtie Antenna [17]

The resistively loaded planner dipole antenna is commonly used in the GPR survey applications [18]. An improved bowtie UWB antenna was developed by Lestari *et al* for the high resolution GPR applications to identify the small shallow-buried objects [18]. This antenna was tested in a commercial GPR system and their result show that this antenna is capable of transmitting of short pulses with the small late-time ringing [18]. This antenna was designed to operate between 0.5-3.0 GHz. There are 13 wires on each sides of this antenna and each one is loaded with 25 surface mounted device (SMD) resistors. These resistors are used for suppression of late-time ringing effect of the antenna. The size of this antenna is 23cm by 7 cm [18]. In addition, the measured result shows that the VSWR of this antenna is less than 2 for frequency range of 1-2 GHz. The figure 11 illustrates the UWB Bowtie Antenna and its VSWR.

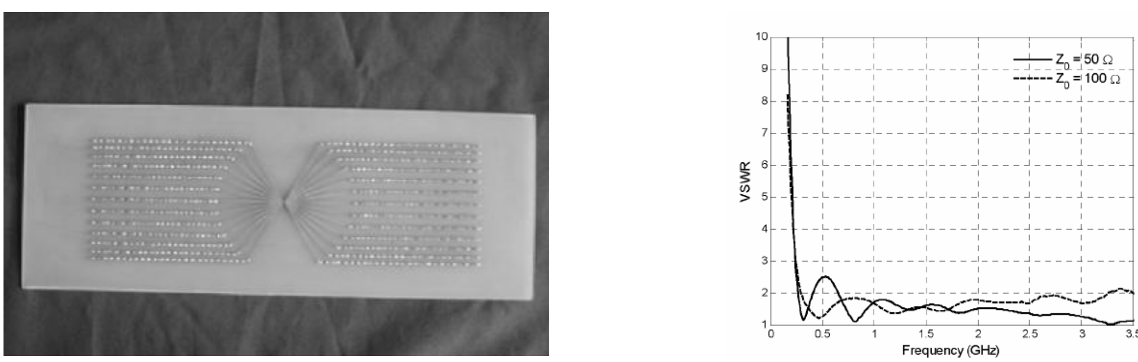


Figure 11: UWB Bow-tie Antenna and Its VSWR [18]

The other type of the bowtie antenna introduced by Lestari *et al.* is adaptive wire bowtie. This type of antenna is more adaptive in compares with common dipoles and bow-ties antenna for GPR applications [19]. This antenna can adapt its input impedance to the different type of soil and variation of distance of the antenna from the ground [19]. This antenna is built from an array of identical dipoles with a common feed point. The angles of the separation in this antenna are 10º, 30 º, 50 º, 70 º, 90 º, 110º, 130 º, and 150 º. The antenna was designed to operate in L-band and S-band frequency spectrum which is suitable for GPR applications. Figure 12 shows this type of the bowtie antenna.

Figure 12: Wire Bowtie [19]

3.1.2 UWB Dielectric Antennas

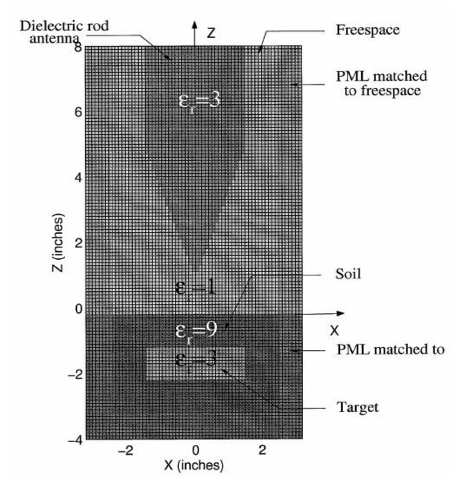


Figure 7: UWB Dielectric-Rod Antenna [9]

The dielectric and dielectric-loaded antennas can be classified as circular cylindrical antennas, conical antennas, spherical antennas, rod antennas, circular and rectangular horn, etc [20]. One UWB dielectric-rod antenna was designed, built and tested by Chen *et al.* [9] to operate at a frequency range from 1 to 6 GHz for GPR application to detect the shallow buried targets such as antipersonnel (AP) mines [9]. In addition, the wave propagation and radiation pattern of this antenna was verified based on a numerical model of finite difference time domain (FDTD) technique. This UWB dielectric-rod antenna designed to operate for near-field measurement. The measured data of the dielectric-rod antenna indicates that radiation pattern first directed along the rod and then radiated out near the end of the rod [9]. Figure 7 shows the UWB dielectric antenna.

Lee *et al* [21] designed an UWB dielectric horn antenna (DHA) which operates at the frequency range of the 2 to 18 GHz with dual-linear polarization. The dual-linear polarization provides same radiation patterns in E and H-plane which makes it suitable for feeding to a reflector. The measured patterns were in agreement with FDTD modeling. The horn body was made out of the low-loss dielectric material, poly-methacrylate (acrylic). The acrylic is one type of the low cost plastic which is easy to fabricate the antenna. In addition, it has good thermal stability. The input impedance of the antenna is 100 Ω which is matched to impedance of the coaxial cable. The antenna has a gain of approximately 5dB within its frequency range of the operation. In addition, this antenna operates with VSWR less than 1.5 [21]. Figure 8 illustrates the UWB dielectric horn antenna.

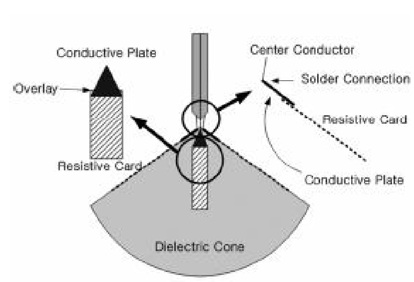


Figure 8: UWB Dielectric Horn Antenna [21]

3.1.4 Horn Antennas

Transverse Electro-Magnetic (TEM) horns are transient antennas [22]. In addition these types of the antennas are good for time domain pulse radiation which is useful for GPR applications [23]. The Yarovoy *et al.* developed one air filled horn for the radiation pattern of 1 ns pulses. The figure 12 shows this antenna.

Figure 13: TEM Horn Antenna [23]

Double-Ridges Guided antennas are similar to TEM Horns as far as their apertures category is concerned. This type of antenna can operate on wide range of frequencies from a few MHz to tens of GHz. One of the double-ridges guided antennas was analyzed and simulated by Bruns *et al.* within frequency range of 1-18 GHz. The simulation was conducted by commercial FEKO software. The result shows that the radiation pattern of this double-ridged guided antenna will change when the operational frequency is greater than 12 GHz. In addition, the conducted simulation were in agreement with the measurement result over 1-18 GHz [24]. Figure 14 presents the radiation pattern of the double-ridges guided antenna.

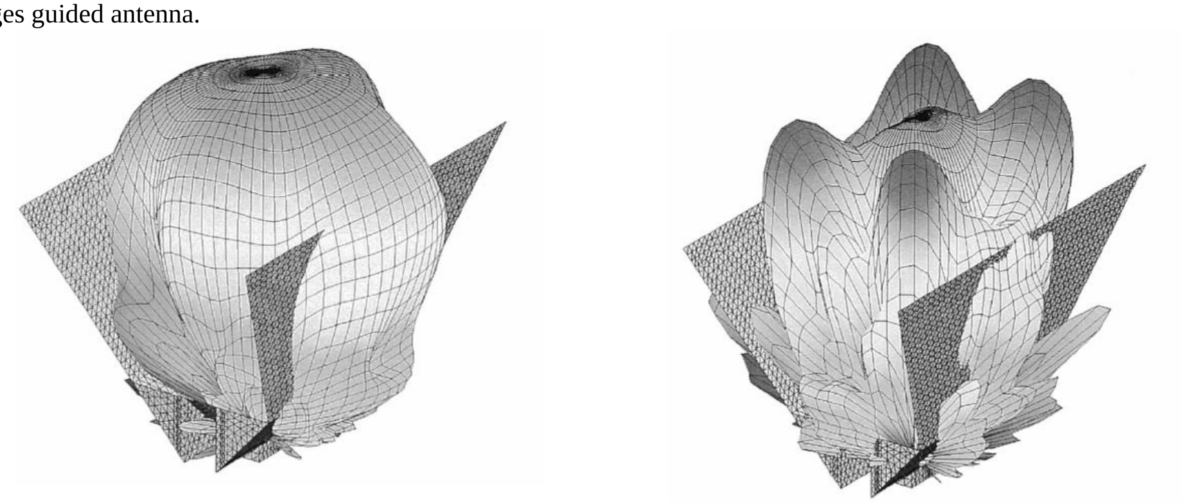


Figure 14: Radiation Pattern of the Double-Ridges Guided Antenna Below and Above 12 GHz [24]

The horn antennas were typically designed and built in large sizes. However, the folded horn antenna for the UWB high power application is introduced by Kardo-Sysoev *et al.* in late 1990s which has smaller size in compare with the other types of horn antennas [6]. Figure 15 illustrates this folded horn antenna. Recently, a folded horn antenna was designed and tested by Farr *et al.* which operates with moderate gain. They reached a gain of at least 10 dB over 3 to 5 GHz for this antenna. Figure 16 shows the types of the folded horn antenna that designed by the Farr [25]. This antenna was designed, in particular, to overcome the size issue of the existing pyramidal horn antennas. This antenna provides the 80% efficiency over an operational frequency range of 3 to 5 GHz. The antenna is powered through a SMA connector. In this design the electrical size of the disc was increased by using dielectric material Teflon (ε_r= 2.1) to reduce the size of the antenna. Radiation pattern of this antenna was shown and compared based on the experiment and numerical analysis. The result shows that the numerical result is in agreement with experimental result, except the experimental data had higher H-plane sidelobe levels than the predicted numerical analysis [25].

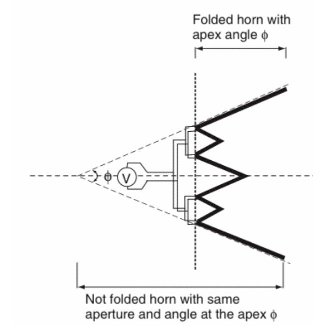


Figure 15: Folded Horn Antenna [6]

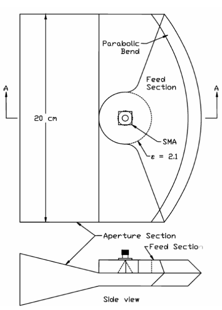


Figure 16: Folded Horn Antenna [25]

3.1.5 Spiral

There are several types of the spiral antennas related in literature. Two common of spiral antennas are: Log Spiral and Archimedean Spiral antennas. These types of the broadband spiral antennas have excellent broadband radiation, and they are compact.

Kramer *et al.* designed a smaller size broadband spiral antenna. To reduce the size of the antenna, they applied a miniaturization process and designed a ceramic-loaded slot spiral antenna [26]. Their antenna design is based on the square Archimedean instead of the circular spiral. In addition, they demonstrate a new feeding technique which allows connecting the radiating slot line to a 50 Ω coaxial cable by a terminating resistor infinite coaxial Balun [26]. The other improvement they proposed included a single resister termination to achieve a good axial ratio performance. This is crucial because if the arm of the spiral antenna was not terminated properly it will cause the refection at the end of the arm by the traveling wave which this will lead to poor cross polarization and axial ratio [26]. During the modification of this antenna was found that a 47 Ω is providing more effective termination. The mentioned improvements are leading to better axial ratio and lower frequency operation [26]. Figure 17 shows the gain measurement of this 2” spiral antenna with resistive taper and single resistor for the frequency range of 0.5 -2 GHz.

In the same vein a finite-ground stripline-based spiral antenna was designed by Huff-Roach. This spiral antenna designed from Rochelle Foam with dielectric constant about 1 (ε_r ~ 1). The antenna was designed to operate between 700 MHz to 4.5 GHz. The figure 18 illustrates the VSWR of this antenna from 0.5-3.0 GHz [27].

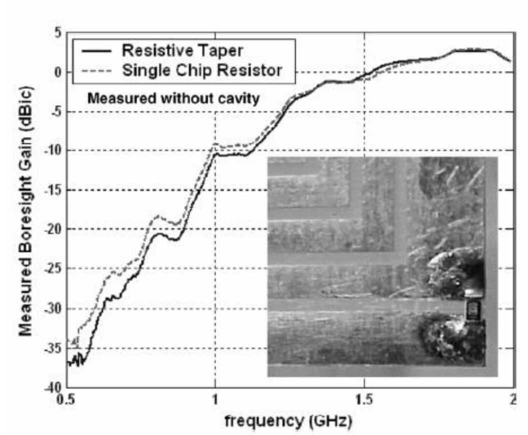


Figure 17: Gain Measurement of the 2” Spiral Antenna [26]

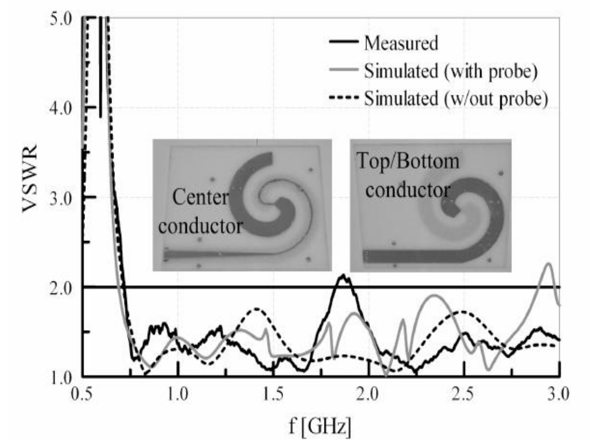


Figure 18: VSWR of the Spiral Antenna [27]

4. COMMERCIALLY AVAILABLE ANTENNAS

4.1 Horn Antennas

This section discusses several available commercially antennas which are operating below 6 GHz in particular within the range of 1-2 GHz. Horn types antennas have good directivity, and they can operates in wide range of frequency from few hundreds MHz to tens of GHz. In addition, these types of the antennas are suitable for applications which are required high gain antenna; however, a typical double-ridged or quad-ridged horn antenna usually weighs from 2 kg to more than 10 kg and they were made in large sizes which make them not a good candidate for portable UWB applications. The other advantage of a horn type antenna is its high power handling.

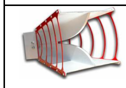
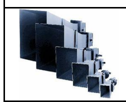
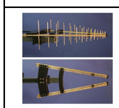
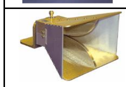
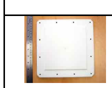
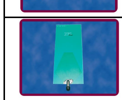
4.2 Log Periodic Antennas

The other commercially available antenna for operating in L-band frequency range is log periodic antenna. This type of antenna has moderate gain in compare with the horn antenna; moreover, some of the log periodic antenna like EM-6956 model has much lighter weight in compare with the horn antennas. This antenna can be suitable for unmanned aerial vehicles (UAV).

4.3 Other Antennas

Those helix antennas that are operating in L-band like AMHP-13-13R/045 and AMHS14-15R/028 are not covering entire the L-band spectrum completely. In addition, these antennas are manufactured in the large sizes.. This antenna has smaller size in compare to other commercially available antennas. The conical log spiral antenna (Model 3102) has a similar size in compare to the horn antennas and provides a gain less than 4. However, it operates with low VWSR. The spiral antenna (903001) provides a high gain but it is not suitable for portable systems because of its size. The model 903-0001 is a broadband dipole blade antenna that has smaller size in compare to the other antennas; however, it provides a lower gain in certain frequencies with in L-band spectrum. Another antenna which is operating in the L-band spectrum is an airborne blade antenna (MT-261002). This antenna is one of the smallest antennas within L-band spectrum.

Table 1. List of Commercial Antennas

	Model / Ref.	Type	Freq. (GHz)	Power (W)	Pol[3]	Gain (dBi)	Pat[4]	Im[5] (Ω)	VSWR	Dim. (cm)	Weight kg (lb)
	3106B [28]	Double-Ridged Guide	0.2 - 2.5	800	L[6]	5-10	D[7]	50	<1.6:1	97.8 x 93.3 x 72.9	11.8 (26.01)
	3115 [29]	Double-Ridged Guide	0.75 - 18	500	L	5-16	D	50	<1.5:1	27.9 x 24.4 x 15.9	1.8 (3.97)
	3102 [30]	Conical Log Spiral	1 - 10	50	C[8]	<4	D	50	1.6:1	38.1 x Dia. 12.7	3.6 (7.94)
	3164-03 [31]	Quad-Ridged Horn	0.4 - 6	50	DL[9]	5-18	D	50	<2.5:1	50.8 x 33 x 33	9 (19.84)
	3161-01 [32]	Octave Horn	1 - 2	550	L	12-18 [33]	D	50	<1.1:1	88.0 x 53.1 x 39.8	8.0 (17.6)
	3164-07 [34]	Quad-Ridged Horn	0.75 - 6	50	L/C	<10	D	50	<3:1	35.5 x 31.1 x 31.1	3.8 (8.38)
	HPA-8003 [35]	Log Periodic Dipole	0.8 - 3	100	L	10	D	50	1.5:1	84 x 32 x 23	2.7 (6)
	HRN-0118 [36]	Double-Ridged Guide	1 - 18	300	L	5-14 [37]	D	50	<1.5:1	29 x 23.4 x 14.5	1.9 (4.2)
	SAS-570 [38]	Double-Ridged Guide	0.17 - 3	800	L	<10.9	D	50	<2.4:1 [39]	93.2 x 72.9 x 97.8	10.21 (22.5)
	AMHP-13-13R/045 [40]	Helix	1.0 – 1.5	-	RHC[10]	13	-	-	-	75.7x Dia. 7.4	-
	AMHS14-15R/028 [40]	Helix	1.3 – 1.7	-	RHC	14	-	-	-	66.6 x Dia.7.0	-
	AMH12-2.1R/1188 [40]	Helix	1.7 – 2.5	-	RHC	12.5 peak, 10.7	-	-	-	38.1 x Dia.12.7	-
	PSA-50200-LP/1211 [41]	Flat Panel and Low Profile	0.5 - 3	-	R. C.	8	-	-	-	49.0 x 39.9 x 3.0	-
	901-0024-001 [42]	Spiral	0.15 - 6	1	C	<8	-	-	<2.5:1	55.25 x 55.25 x 1.9	1.45 (3.19)
	903-0001-001 [42]	Broadband UHF Dipole	0.6 - 2	10	L	<4	-	-	<3:1	22.7 x 8.8 x 1.6	0.065 (0.143/ 2.3 oz)
	EM-6956 [44]	Log Periodic	0.5 - 3	5	-	-	-	50 N	<1.3:1	26.0 x 20.3 x 3.2	0.454 (1)
	MT-261002 [45]	-	0.5 - 2	100 CW	V[11]	3.5	-	50	<2.5:1	10.1 x 6.6 x 11.8	0.255 (0.562)

[3] Polarization, [4] Patten Type, [5] Impedance, [6] Linear, [7] Directional, [8] Circular, [9] Dual Linear, [10] Right Hand Circular, [11] Vertical

5. CONCLUSION

A large array of commercial and non-commercial UWB antennas was surveyed and discussed in this paper. Each of these antennas offers its own pros and cons. The fat dipole, the cross dipole, and the rolled dipole antennas presented in this paper operate on upper VHF and lower UHF spectrum which is suitable for deep ground penetrating radar. The rolled dipole has a larger size in compare to first two former antennas. In other hand, the RVD antenna is operating in wider frequency spectrum from 100 MHz to 10 GHz which is suitable for wide variety of UWB applications including GPRs. The RVD antenna has several advantages like having low VSWR < 2 and high efficiency. The antenna efficiency is essential factor for far-field applications like airborne (remote sensing) GPR. In addition, the RVD is lightweight antenna and has low RCS which makes it good candidates for the antenna array applications. Bowties antenna is one of most common antenna which is used in the GPR application. All of the bowtie antennas in this survey operate within L-band. The RC loaded bowtie antenna provides high radiation efficiency. In other hand, the adaptive wire bowtie antenna can adapt its input impedance to variation of distance of the antenna from the ground which is suitable for portable GPR system, but the length of the antenna is 50 cm which is a disadvantage for the portable GPR systems. Among the dielectric-loaded antennas the UWB dielectric-rod antenna and the UWB dielectric horn antenna were discussed in this paper. The UWB dielectric-rod operates within frequency range of 1-6 GHz. In addition, this antenna designed for near-field measurement, therefore, it is not recommended for the far-field GPR (remote sensing) applications. The Lee *et al* UWB horn antenna design operates within wider frequency range from 2 to 18 GHz with VSWR less than 1.5. The other advantage of this antenna is its dual-linear polarization which makes it a good candidate for feeding a reflector. However, it has lower gain compared with most of commercially available horn antennas such as double-ridged guide horn antennas, quad-ridged guide horn antennas, octave horn antennas, etc. The folded horn antenna by Farr *et al.* in this survey has a smaller size in compare to other horn antennas but provides a similar gain. The spiral antennas operate in the L-band frequency which is suitable for the GPR systems. However, these antennas are less directional, therefore, are not recommended for the far-field GPR applications. Among the commercial antennas discussed in this paper the horn antennas typically offer a respectable higher gain. In the other hand, the antennas with higher gain have tendency to transmit and receive the noises with higher gain factor as well. Within the L-band range, the helix antennas, in particular offer advantageous characteristics (i.e., higher gain, more directivity, and low VSWR). However, they usually operate within portion of the L-band spectrum. Since the directivity is one of the desirable factors for the remote sensing GPR, the selected antenna should provide a good directivity. The higher directivity can achieved by using more directional antenna such as horn antennas or set of the antennas used in the array pattern to achieve more directional antenna. In case of the portable radar systems, array of patch antennas offer a suitable alternative option. The other option would be enhancement of vee dipoles, spiral, or log periodic antennas which are lightweight in compare to larger UWB antennas.

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